Removal of Copper and Cadmium from Aqueous Solution by Adsorption on Coconut Coir Carbon

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

December 2008

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2008

ABSTRACT

Adsorption is one of the most economically effective processes to remove high concentration of heavy metals from wastewater. Commercial activated carbon is expensive in manufacturing and regenerating. In this study, activated carbon prepared from coconut coir is investigated by observing its efficiency to adsorb copper and cadmium from aqueous solution. Using the batch adsorption technique, parameters such as contact time, pH, carbon dose and concentration of metal in solution on removal was studied. The characteristic of the prepared coconut coir activated carbon was analyzed by measuring its pH, apparent density, moisture content and ash content. The adsorption data for both coconut coir activated carbon and commercially activated carbon (F-400) were fitted to Langmuir and Freundlich isotherm models. From the batch studies conducted, higher adsorption was seen for the lower initial concentration of copper and cadmium ion. The percentage of ion removal also increased with increasing contact time. The effect of pH and carbon dose also was been studied. The uptake of metal ion is lower in acidic condition and increases with increasing pH. As the carbon dose increases, the percentage of metal removal also increases. Comparing the characteristics of coconut coir activated carbon with coconut coir pith activated carbon (Santhy and Selvapathy, 2004), pH of both carbons is almost the same. Yet the prepared coconut coir activated carbon has higher ash content and is heavier compared to coconut coir pith activated carbon. From the adsorption isotherm, it is seen that the coconut coir activated carbon has higher adsorption capacity compared to F-400. Yet, F-400 has higher adsorption rate compared to coconut coir activated carbon.

ACKNOWLEDGEMENT

First of all, I would like to praise Allah SWT for the blessings and guidance given to me in order to accomplish the Final Year Project.

Throughout the whole period conducting this project, many had provided immeasurable amount of guidance, ideas, assistance, support and advice. Greatest appreciation is expressed to my supervisor, Professor Malay Chaudhuri for his constant guidance and constructive ideas in completing this project successfully.

Secondly, I would like to take this opportunity to thank Mr. Welly Herumutri and Dr. Amir Hossein Malakahmad for they willingness to sacrifice their precious time and sharing their great knowledge with me in order to make sure this project is successful.

Not forgotten to all Civil Engineering Department lecturers for their help in sharing their valuable experiences and knowledge in helping me completing this project. Deepest appreciation to all Civil, Chemical and Mechanical Engineering Department technicians who have assist me directly and indirectly through out this project.

Last but not least, I would like to thank my family, friends and everyone who have contributes in this project and gave motivation and encouragement which enable me to complete this project within the time given.

Thank you.

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LIST OF ABBREVIATION & NOMENCLATURES

ABBREVIATION

AAS	Atomic Absorption Spectrophotometer
ASTM	American Standard Test Method
MCL	Maximum Contaminant Level
PPE	Personal Protective Equipment
US	United States

NOMENCLATURES

Cd	Cadmium
Cd(II)	Ion Cadmium(II)
$CdSO_4.H_2O$	Cadmium (II) Sulfate Hydrate
CO_2	Carbon Dioxide
Cu	Copper
Cu(I)	Ion Copper (I)
Cu(II)	Ion Copper (II)
$Cu_2(OH)_2CO_3$	Malachite (Copper Basic Carbonate)
$CuSO_4.5H_2O$	Copper (II) Sulfate Pentahydrate
HCl	Acid Hydrochloric
Hg	Mercury
KOH	Potassium Hydroxide
NaOH	Sodium Hydroxide
NO_2	Nitrogen Dioxide
SO_2	Sulfur Dioxide

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Heavy metals such as cadmium, copper, zinc and lead are used in many industries including metal plating and finishing, petroleum refining and organic chemical production. The widespread used of these metals has lead to concern over detrimental effects on human health and the environment as of their characteristic which are highly toxic, non-biodegradable and have a probable carcinogenic effect [1]. The promulgation of direct discharge standards as well as pretreatment standards for the discharge of industrial waste into wastewater, has aimed at controlling these metal concentrations. With this regulatory incentive, much interest has been replaced upon the development and improvement of removal technologies, including chemical precipitation, electrodialysis, adsorption, ion exchanger, solvent extraction, and others [2].

Adsorption by activated carbon is an established treatment method for organic contaminants but has been rarely used in actual treatment setting for inorganic absorbents, despite the fact that the ability of activated carbons to remove heavy metals has been established by numerous researchers. For this study, coconut coir is used as the activated carbon for treatment of the metal ions inside waste stream. This agriculture by-product which is generated in billions of kilograms annually is potential to be best metal absorbing carbon as it has the "soft", low density characteristics [3].

1.2 Problem Statement

The most economical process to remove waste with high metal concentrations is precipitation process. Yet, this process has a major drawback which is the sludge production [4]. Conventional technologies such as precipitation, filtration, reverse osmosis, oxidation-reduction, and membrane separation are often inadequate to reduce heavy metal concentrations to acceptable regulatory standards [5]. It becomes clear that a cost-effective secondary polishing treatment process is needed for the removal of heavy metals at dilute concentrations. Ion exchange is considered a better alternative technique for such a purpose. However, it is not economically appealing because of high operational cost. Commercial activated carbon adsorption is considered to be a particularly competitive and effective process for the removal of heavy metals at trace quantities; however, the use of commercial activated carbon is not suitable in developing countries due to the high costs associated with production and regeneration of spent carbon [6]. Adsorption process can be economically effective if low cost activated carbon is used. Natural materials those are available in large quantities or certain waste from agricultural operations such as coconut coir have potential to be used as raw material to prepare low cost activated carbon, as they represent unused resources, widely available and are environmentally friendly.

1.3 Objectives and Scope of Study

The primary objectives of this study are:

- To determine the efficiency of coconut coir activated carbon to remove copper and cadmium from aqueous solution
- To compare the effectiveness of the prepared coconut coir activated carbon with the commercial activated carbon (F400).

The scope of work for this project is to study the removal efficiency of the adsorption process using coconut coir carbon. Two tests are conducted; batch studies and column studies. In the batch studies, effect of solution concentration, contact time, pH and carbon dose on metal adsorption will be observed. Column studies will be conducted to determine how this carbon will perform in a dynamic process. In these studies, experiments will be conducted to observe the effect of flow rate and bed depth on the removal of metal ions. Both of these studies will determine the effectiveness as well as the efficiency of the coconut coir activated carbon.

1.4 Relevancy of the Project

Coconut coir which is one of agriculture by-products and locally available is economically effective in manufacturing of activated carbon. Though commercial activated carbon is a well known adsorbent for the removal of heavy metal from water and wastewater, the high cost in manufacturing of this activated carbon limits its use in a developing country. The properties of coconut coir which is low in density and high volatile content, is very suitable to produce low density activated carbon. The char obtained from coconut coir can be activated easily to produce reasonably high quality activated carbon.

1.5 Feasibility of the Project

The preparation of the material is the most crucial part in this research. To obtain a high quality activated carbon, every stage in the preparation process needs to be done properly. The preparation of high quality activated carbon is estimated to be completed within three months. The batch studies using aqueous solution will be conducted after the coconut coir activated carbon is obtained. Only when the result obtained from the batch studies is favorable, the author will proceed with the column studies. The preparation of the activated carbon is done continuously for the first six month of the research period until the high quality carbon is obtained.

The commercially activated carbon, F200 which is obtained for the manufacturer will be tested to compare its performance with the coconut coir activated carbon. The gantt chart of the project is attached in Appendix I.

CHAPTER 2

LITERATURE REVIEW

2.1 Adsorption

2.1.1 Adsorption Theory

Adsorption phenomena are operative in most natural physical, biological, and chemical systems. Its operations employing solids such as activated carbon and synthetic resins are used widely in industrial applications as well as for purification of water and wastewaters.

The process of adsorption involves separation of a substance from one phase accompanied by its accumulation or concentration at the surface of another. The adsorbing phase is the adsorbent, and the material concentrated or adsorbed at the surface of that phase is the adsorbate. Adsorption at the surface or interface is largely the result of binding forces between the individual atoms, ions, or molecules of an adsorbate at the surface, all of these forces having their origin in electromagnetic interactions. [7]

2.1.2 Adsorption Principles

The adsorption principles can be distinguished into four types - exchange, physical, chemical, and specific. Exchange adsorption, or ion exchange, involves electrostatic attachment of ionic species to sites of opposite charge at the surface of adsorbent, with subsequent displacement of these species by other ionic adsorbates of greater electrostatic affinity.

Physical adsorption results from the action of Van der Waals forces, which are comprised of both London dispersion forces and classical electrostatic forces.

Chemical adsorption involves a reaction between an adsorbate and an adsorbent resulting in a change in the chemical form of adsorbate. The resulting chemisorptive bond is usually stronger than that derived from the physical Van der Waals forces.

The last adsorption principle which is specific type is attachment of adsorbate molecules at functional groups on adsorbent surfaces which do not result in adsorbate transformation. [8]

2.1.3 Adsorption Process

Adsorption process takes place in at least four definable steps which are bulk solution transport, film diffusion transport, pore transport and adsorption.

Bulk solution transport involves the movement of the organic material to be adsorbed through the bulk liquid to the boundary layer of fixed film of liquid surrounding the adsorbent, typically by advection and dispersion in carbon contractors.

Film diffusion transport involves the transport by diffusion of the organic material through the stagnant liquid film to the entrance of the pores of the adsorbent.

Pore transport involves the transport of the material to be adsorbed through the pores by a combination of molecular diffusion through the pore liquid or by diffusion along the surface of the adsorbent.

Adsorption involves the attachment of the material to be adsorbed to adsorbent at an available adsorption site. Adsorption can occur on the outer surface of the adsorbent and in macropores, mesopores, micropores and semimicropores, but the surface area of the macro and mesopores is small compared with the surface area of the

micropores and semimicropores and the amount of material adsorbed there is usually considered negligible. [10]

2.1.4 Adsorption Solution-Solid

Adsorption from solution onto a solid thus can occur as a result of one or both of two characteristics properties for a given solvent-adsorbate-adsorbent system. Thus, adsorption will be affected by a number of parameters specific to a given system.

For the adsorbate they include concentration, molecular weight, molecular size, molecular structure, molecular polarity, steric form of configuration, and the nature of the background of the competitive adsorbates. For the adsorbent the most important determinants of equilibrium capacity and rate of approach to this capacity include surface area, the physicochemical nature of the surface, the availability of that surface to adsorbate molecules or ions, and the physical size and form of the adsorbent particles [9].

2.1.5 Adsorption by Activated Carbon

Physical adsorption is the primary means by which activated carbon works to remove contaminants from water. Carbon's highly porous nature provides a large surface area for contaminants (adsorbates) to collect. In simple terms, physical adsorption occurs because all molecules exert attractive forces, especially molecules at the surface of a solid (pore walls of carbon), and these surface molecules seek other molecules to adhere to. The large internal surface area of carbon has many attractive forces which work to attract other molecules. Thus contaminants in water are adsorbed (or held) to the surface of carbon by surface attractive forces similar to gravitational forces.

Adsorption from solution occurs as a result of differences in adsorbate concentration in the solution and in the carbon pores. The adsorbate migrates from the solution

through the pore channels to reach the area where the strongest attractive forces are. Water contaminants adsorb because the attraction of the carbon surface for them is stronger than the attractive forces that keep them dissolved in solution. Those compounds which are more adsorbable onto activated carbon generally have a lower water solubility, are organic (made up of carbon atoms), have a higher molecular weight, and a neutral or non-polar chemical nature. It should be pointed out that for water adsorbates to become physically adsorbed onto activated carbon, they must be both dissolved in water and smaller than the size of the carbon pore openings so that they can pass into the carbon pores and accumulate.

Besides physical adsorption, chemical reactions can occur on a carbon surface. One such reaction is chlorine removal from water involving the chemical reaction of chlorine with carbon to form chloride ions. This reaction is important to POU treatment because this conversion of chlorine to chloride is the basis for the removal of some common objectionable tastes and odors from drinking water.

2.1.6 Adsorption Isotherm

The theoretical adsorption capacity of the carbon for a particular contaminant can be determined by developing its adsorption isotherm. Adsorption isotherms are developed by exposing a given amount of adsorbate in a fixed volume of liquid to varying amount of activated carbon. Typically more than ten containers are used which will be equilibrate into certain contact time. At the end of the test period the adsorbent phase concentration is measured. Two most common isotherms which used to describe experimental isotherm data are Freundlich and Langmuir isotherm.

Freundlich isotherm is the most commonly used isotherm to describe the adsorption characteristic of activated carbon used in water and wastewater treatment. This isotherm which derived empirically in 1912 is defined as below:

$$\frac{x}{m} = K_f C_e^{1/n}$$

where $\frac{x}{m}$ = mass of the adsorbate adsorbed per unit mass of adsorbent, mg adsorbent per g of activated carbon

K_f = Freundlich capacity factor, (mg adsorbate/g activated carbon) (L water/ mg adsorbate) $^{1/n}$

C_e = equilibrium concentration of adsorbate in solution after adsorption, mg/L

$1/n$ = Freundlich intensity parameter

The constant in Freundlich isotherm can be determined by plotting log *(x/m)* versus log C_e and making use of previous equation rewritten as:

$$\log\left(\frac{x}{m}\right) = \log K_f + \frac{1}{n}\log C_e \qquad [10]$$

Another isotherm which is common in water and wastewater treatment is Langmuir adsorption isotherm. This isotherm is defined as:

$$\frac{x}{m} = \frac{abC_e}{1 + C_e}$$

where $\frac{x}{m}$ = mass of the adsorbate adsorbed per unit mass of adsorbent, mg adsorbent per g of activated carbon

a, b=empirical constant

C_e = equilibrium concentration of adsorbate in solution after adsorption, mg/L

The Langmuir adsorption isotherm was developed by assuming

- A fixed number of accessible sites are available on the adsorbent surface, all of which have the same energy, and
- Adsorption is reversible. Equilibrium is reached when the rate of adsorption of molecules onto the surface is the same as the rate of desorption of molecules from the surface.

The constant in the Langmuir isotherm can be determined by plotting $C_e/(x/m)$ versus C_e and making used the previous equation rewritten as:

$$\frac{C_e}{\left(x/m\right)} = \frac{1}{ab} + \frac{1}{a}C_e$$

2.2 Heavy Metals

The "heavy metals" is defined as a metal with density greater than 5 g/cm^3 or specific gravity exceeding 5 [11]. The accumulation of heavy metals in the pedosphere and lithosphere is a great concern since, contrary to organic compounds; they are not subjected to any degradation. Heavy metals are the most common of all metabolic poisons as they can affect human's enzymes, the cellular protein that regulate many important chemical reaction in human's body.

The mobility of heavy metal pollutants depends mainly on the complex network of interactions between aqueous and heterogeneous chemical reactions as well as particle coagulation and flocculation phenomena. Hydrolysis and dissolved complexation tend to increase the solubility of heavy metals while precipitation and adsorption will delay metal availability and transport. [12]

2.3 Copper

2.3.1 Copper Metal and Ion

Copper is often called the "coinage metals' because it has been used for the purpose since ancient times. It can be found in nature as free metals, a reflection of its stability. Copper (Cu) is widely distributed in nature in ores containing sulfides, arsenides, chlorides, and carbonates. A reddish-brown, malleable, ductile metal, copper is valued for its high electrical conductivity and resistance to corrosion. It is used in plumbing and electrical applications. The reddish colored metal oxidizes slowly in air; when CO_2 is also presents, its surface becomes coated with green film of $Cu_2(OH)_2CO_3$. Copper principally exists in the +2 oxidation state, but compounds containing Cu(I) ion are also known.

Shown in Figure 1 is the world production trend of copper which is taken from U.S Geological Survey.

Figure 1: World production trend of copper

2.3.2 Copper in Environment

Although trace amounts of copper are essential for life, copper in large amount is quite toxic. The toxicity of copper is applied in certain condition such as copper salts are used to kill bacteria, fungi, and algae, and paints containing copper are used on ship hulls to prevent fouling by marine organisms. [11]

The maximum contaminant level (MCL) of copper in drinking water is 1.0 mg/L. The average copper content of drinking water is 0.61 to 250 μg/L, and this amount has increased over time due to pipe corrosion and chlorination. Typical discharge limits for copper found in secondary effluent in wastewater treatment is 4.9 μg/L daily [10]. Acute exposure overdose to this metal ion causes an immediate metallic taste, followed by epigastric burning, nausea, vomiting, and diarrhea. Fatal cases often include secondary effects such as hypertension, shock, and coma. [11]

Toxicity can occur from eating acid food that had been cooked in Copper cookware. Cirrhosis of the liver in children has been linked to boiling milk in copper cookware. In addition, studies have found that people with mental illnesses such as schizophrenia had heightened levels of copper in their systems. However it is unknown at this stage whether the copper contributes to the mental illness, whether the body attempts to store more copper in response to the illness, or whether the high levels of copper are the result of the mental illness.

Too much copper in water has also been found to damage marine life. The observed effect of these higher concentrations on fish and other creatures is damage to gills, liver, kidneys, and the nervous system. It also interferes with the sense of smell in fish, thus preventing them from choosing good mates or finding their way to mating areas.

2.4 Cadmium

2.4.1 Cadmium Metal and Ion

Cadmium is less abundant compared to zinc and is usually found as an impurity in zinc ores. The free metal is soft and moderately active. It is mainly use as a protective coating on other metals, including metals exposed to an alkaline environment, and for making nickel-cadmium batteries.

Shown in Figure 2 is the world production trend of cadmium which is taken from U.S Geological Survey.

Figure 2: World production trend of cadmium

2.4.2 Cadmium in Environment

Cadmium may contaminate water supplies from mining, industrial operations, and leachate from landfill. It also may enter water distribution systems through corrosion of galvanized pipes. Airborne cadmium comes primarily from the steel industry and water incineration, followed by volcanic activity and zinc production.

Daily consumption of cadmium varies from 17 to 64 μg according to various national estimates. Concentrations in drinking water range from 0.2 to 0.7 μg/L. Typical discharge limits for cadmium found in secondary effluent in wastewater treatment is 1.1 μg/L daily[10].

Acute exposure to cadmium fumes may cause flu like symptoms including chills, fever, and muscle ache sometimes referred to as "the cadmium blues." Symptoms may resolve after a week if there is no respiratory damage. More severe exposures can cause tracheo-bronchitis, pneumonitis, and pulmonary edema. Symptoms of inflammation may start hours after the exposure and include cough, dryness and irritation of the nose and throat, headache, dizziness, weakness, fever, chills, and chest pain.

Inhaling cadmium-laden dust quickly leads to respiratory tract and kidney problems which can be fatal (often from renal failure). Ingestion of any significant amount of cadmium causes immediate poisoning and damage to the liver and the kidneys. Compounds containing cadmium are also carcinogenic.

The bones become soft (osteomalacia), lose bone mineral density (osteoporosis) and become weaker. This causes the pain in the joints and the back, and also increases the risk of fractures. In extreme cases of cadmium poisoning, the mere body weight causes a fracture.

The kidneys lose their function to remove acids from the blood in proximal renal tubular dysfunction. The kidney damage inflicted by cadmium poisoning is irreversible and does not heal over time. The proximal renal tubular dysfunction creates low phosphate levels in the blood (hypophosphatemia), causing muscle weakness and sometimes coma. The dysfunction also causes gout, a form of arthritis due to the accumulation of uric acid crystals in the joints because of high acidity of the blood (hyperuricemia). Another side effect is increased levels of chloride in the blood (hyperchloremia). The kidneys can also shrink up to 30%. Other patients lose their sense of smell (anosmia) [11].

The high toxicity of cadmium was observed for the first time in Japan in 1955 (disease of Itai-Itai). A mine poured its used water, polluted by cadmium, in a river being used for the irrigation. The polluted rice consumers are reflected to suffer from immunizing deficiencies, renal attacks, apathy, pains in the members and deformations of the skeleton [12].

2.5 Activated Carbon

2.5.1 Definition

Activated carbon is amorphous carbon based material prepared to exhibit a high degree of porosity and an extended interparticulate surface area. Due to a high degree of microporosity, just one gram of activated carbon has a surface area of approximately 500 m^2, as determined typically by nitrogen gas adsorption [14]. These are obtained by combustion, partial combustion, and thermal decomposition of various carbonaceous substances.

The primary raw material used for activated carbon is any organic material with high carbon content (coal, wood, peat, coconut shells). The carbon-based material is converted to activated carbon by thermal decomposition in a furnace using a controlled atmosphere and heat.

The resultant product has an incredibly large surface area per unit volume, and a network of submicroscopic pores where adsorption takes place. The walls of the pores provide the surface layer molecules essential for adsorption.

2.5.2 Activated carbon principle

Carbon has several forms in nature. The two best known crystalline structures of carbon are graphite, which is a flat hexagonal structure, and diamond which is a

tetrahedral form. Activated carbon consists of a random, but locally semi-organized, number of these graphite platelets.

The force that fixes the products to be adsorbed is called the London dispersion force. This force is in fact a form of Van der Waals force, one of the four elementary forces in nature. The force is very strong, but only over short distances. The force is equal between all carbon atoms and is not dependent on outside parameters such as temperature and pressure. When considering this it can understand that adsorbate molecules will be held most strongly where they are surrounded by the most carbon atoms.

The average distance between the adsorbate molecule and the surrounding graphite platelets will govern the strength of the adsorption force. As can be seen from Figure 3, some regions have a high density of graphite plates, and molecules in these areas will be subject to very high adsorption forces. Conversely there are areas with a lower density of platelets and these will exhibit lower adsorption forces. During adsorption those areas having the highest adsorption potential are occupied first and molecules adsorbed in these regions tend to be more strongly held than molecules adsorbed in areas with a lower adsorption potential. Raw material and production processes used in the manufacture of activated carbon are the basis for the different physical properties and pore size distributions found in commercial grades of carbon. [15]

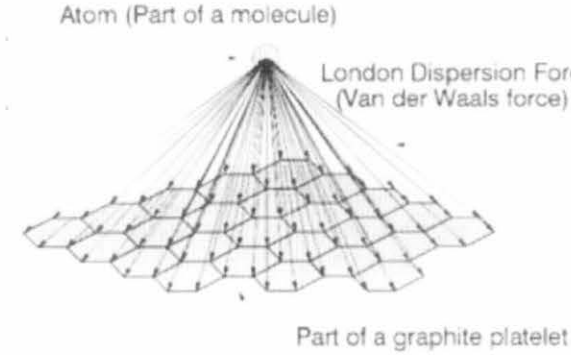


Figure 3: Activated carbon principle

2.5.3 Application in Industries

This material is extensively used to purify, decolorize, deodorize, dechlorinate, and detoxicate potable waters. It is also being used for solvent recovery, and air purification in inhabited spaces such as restaurant, food processing and chemical industries. Activated carbon also is used in variety gas phase applications. In hydrometallurgy, activated carbon is used for the recovery of gold and silver and other inorganics and in the treatment of domestic and industrial wastewaters. Its use in medicine for certain types of bacterial ailments is well known [15].

2.5.4 Physical properties

Activated carbon products can be characterized by physical properties and activity properties. Both physical and activity properties become important factors in the specification of commercial carbons for POU applications. Important physical properties are surface area, product density, mesh size, abrasion resistance and ash content. In water treatment applications, carbon density is expressed as back-washed and drained (BWD) or bulk density. This establishes the number of pounds of carbon required to fill a back-washable filter, and is expressed in terms of pounds per cubic foot.

Mesh size establishes the range of particle sizes and thus, the effective particle size which will be used in a filter. Particle size is an important parameter in specifying carbons for specific applications, affecting such operating conditions as pressure drop, filtration capabilities, backwash rate requirements and the rate of adsorption of contaminants. While a smaller particle size effects more pressure drop across a carbon bed, the rate of diffusion of an organic into the pore and its subsequent adsorption is significantly increased.

Another important characteristic that distinguishes different types of liquid phase carbons is abrasion resistance. Abrasion resistance refers to a carbon's ability to

withstand degradation during handling and is expressed in terms of abrasion number. The higher the abrasion number, the more resistant the carbon is to abrasion.

The final important physical property of activated carbon is ash level, which reflects the purity of the carbon. It is the inorganic residue left after heating of the raw material. Common as constituents of coal-based carbons are silica, alumina, iron, calcium and magnesium.

Activity characterizations are key indicators of a carbon's potential performance for removing contaminants from water. An important characterization tool used in determining the ability of a carbon to adsorb a particular adsorbant is the pore size distribution, which is usually depicted in the form of a curve as shown in Figure 4. The pore size distribution is produced through adsorption of gases and liquids under pressure. It defines the available pore volume of a carbon over three pore size regions: The micropore region (less than 100 Angstroms* in size), mesopore region (between 100 and 1,000 Angstroms), and macropore region (greater than 1,000 Angstroms).

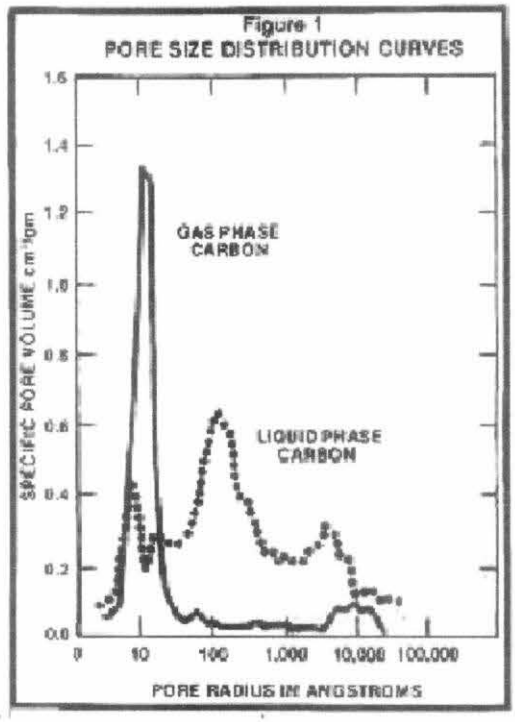


Figure 4: Pore size distribution curve

2.5.5 Classification

Activated carbons are unique and versatile adsorbents because of their extended surface area, microporous structure, universal adsorption effect, high adsorption capacity, and high degree of surface reactivity. Due to complexity of this material, it is difficult to classify it based on its behavior, surface characteristics, and properties. The only parameter that can give an idea the quality of the carbon is its adsorption capacity and particles sizes. On the basis of activated carbon particle size, it can be classified into five main groups; powdered, granulated, spherical, impregnated, or polymer-coated activated carbon. [15]

Powdered activated carbon has a fine granulometry less than 100 μm with average diameter between 15 to 25 μm. Thus, it presents a large external surface and a small diffusion distance. The rate of adsorption is very high and the problems related to mass transfer are very low. [15]

Granulated activated carbon has a relatively larger size of carbon particles in the granules compared to carbon powder and the consequently present smaller external surface. Diffusion of the adsorbate thus is an important factor. This carbon is therefore preferred for the adsorption of gases and vapors as its rates of diffusion is faster. Granulated activated carbon is most commonly produced by grinding the raw material, adding a suitable binder to give it hardness, re-compacting and crushing to the correct size. [15]

The spheres activated carbon which is prepared from pitch has high mechanical strength and excellent SO_2 and NO_2 adsorption capacities. Spherical activated carbon is obtained in two forms which are bellow spheres and granulated spherical pellets. [15]

Impregnated carbon is type of carbon which contains several types of inorganic or organic impregnated. Inorganic impregnated is such as iodine, silver, cations such as aluminium, zinc, iron, lithium, and calcium. Example of organic impregnates are

pyridines, ketones, and tertiary amines. This type of carbon can be used as catalysts to remove gas steam such as SO_2 and NO_2. [15]

Polymer-coated carbon is processed by which a porous carbon can be coated with a biocompatible polymer to give a thin, smooth, and permeable coating without blocking the pores. The resulting carbon is useful for hemoperfusion. [15]

Shown in Table 1 is the comparison of granular and powdered activated carbon. The specific values of every parameter will depend on the source material used for the production of activated carbon.

Table 1: Comparison of granular and powdered activated carbon [10]

Parameter	**Unit**	**Type of activated carbon**	
		GAC	**PAC**
Total surface area	m^2/g	700-1300	800-1800
Bulk Density	kg/m^3	400-500	360-740
Particle density, wetted in water	kg/L	1.0-1.5	1.3-1.4
Particle size range	mm(μm)	0.1-2.36	(5-50)
Effective size	mm	0.6-0.9	-
Uniformity coefficient	UC	≤1.9	-
Mean pore radius	Å	16-30	20-40
Iodine number		600-1100	800-1200
Abrasion number	minimum	75-85	70-80
Ash	%	≤8	≤6
Moisture as packed	%	2-8	3-10

2.5.6 Manufacturing of Activated Carbon

The manufacture of activated carbons involves two main steps: the carbonization of the carbonaceous raw material at temperature below 800°C in the absence of oxygen and the activation of the carbonized product. All carbonaceous material can be

converted into activated carbon, although the properties of the final product will be different, depending on the nature of the raw material used, the nature of the activating agent, and the conditions of the activating process.
During the carbonization stage, the raw material is heated under a time schedule with a certain rate of heating in order to eliminate the volatiles and to form a fixed carbon mass with a rudimentary pore structures. In this stage most of the noncarbon elements such as oxygen and hydrogen are eliminated as volatile gaseous products by the pyrolytic decomposition of the starting material.

The pore structure inside activated carbon is developed during activation stage of the carbon. Activation is an oxidation reaction at elevated temperatures where the oxidizing agent is usually steam and carbon dioxide or sometimes air.

Carbonization and activation stages are sometimes conducted simultaneously using chemical activating agent such as phosphoric acid, zinc chloride, and sulfuric acid. These activating agents act as dehydrating agents as well as oxidants so that carbonization and activation stage can take place simultaneously. [15]

2.6 Heavy metal removal by Activated Carbon

Factor affecting heavy metal removal by activated carbon include: solution pH, metal type and concentration, surface loading, presence of complexing ligands and competing adsorbents, ionic strength, temperature, and carbon type. [16]

For uncomplexed cationic heavy metals, removal increases with increasing pH. When the heavy metal exists as an anion, removal generally increases with decreasing pH. Specifically, the pH effects the status of the outer hydration sheaths of the metal ion, aqueous metal specification, complexation and solubility and the electrochemical behavior of the carbon surface.

The concentration of metal ion affects the removal mechanism as well as the metal surface loading. If the concentration of the cationic metal ion is high enough, then surface precipitation can occur. If the metal concentration is less than the metal's solubility, then the primary removal mechanisms are sorptive in nature.

The presence of complexing ligands and competing adsorbates can alter metal removal from that observed in the metal-only system. Factors determining the effect of ligand have on metal adsorption included type and concentration of ligand and metal, carbon type and solution pH.

2.7 Commercial Activated Carbon (F-400)

Filtrasorb 400 is two high activity granular activated carbons developed by Calgon Carbon Corporation for the removal of taste and odor compounds and dissolved organic compounds from water treatment.

These activated carbons are made from selected grades of bituminous coal to produce a high activity, durable granular product capable of withstanding the abrasion associated with repeated backwashing, air scouring and hydraulic transport. Shown in Table 2 are the specifications of this carbon.

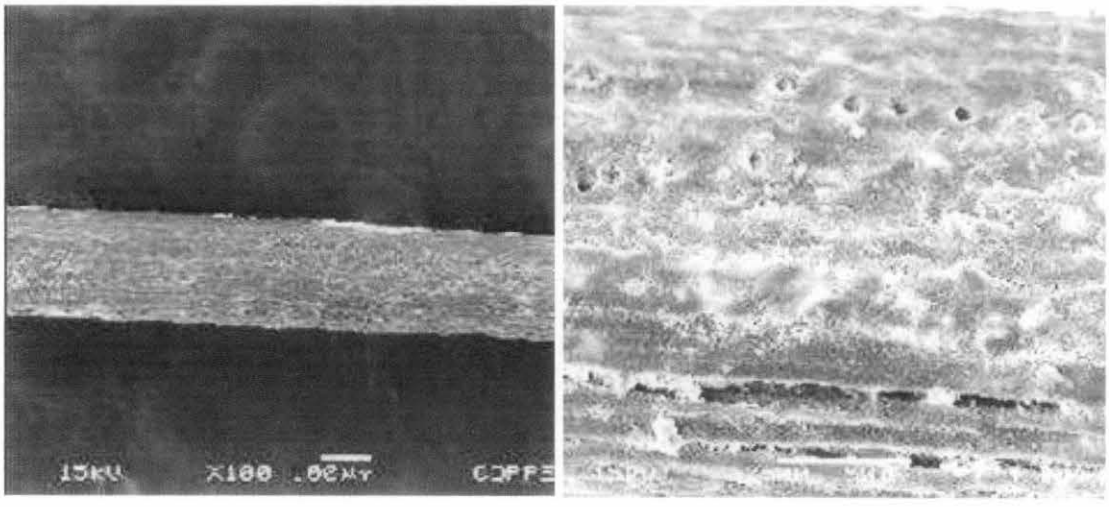
Table 2: Characteristic of F-400

Parameter	Unit	F-400
Iodine number	mg/g	1000
Moisture content (Max.)	%	2
Abrasion Number (Min.)		75
Effective Size	mm	0.55-0.75
Uniformity Coefficient		1.9
Ash Content (Max.)	%	9
Apparent Density(Min.)	g/cc	0.44

2.8 Coconut coir characteristic

Coir is a natural fiber derived from the husk of the coconut. The husk contains fiber and fine materials that constitute coco peat. Coir fiber is a homogenous material comprised of millions of capillary micro-sponges resulting in high water absorption and retention capacity. It is commercially proven as a high quality renewable alternative to mined peat moss, and its supply slows down peat extraction from environmentally sensitive swamp areas.

The aspect of a coir fiber observed by SEM is shown in Figure 5 with different magnifications. The fiber surface is covered with protrusions and small voids. Coarse pithy tissue particles (larger than 1 mm) were highly porous, with an internal porosity of 41.0% by volume. These particles exhibited round-shaped external pores which ranged in diameter from 30 to 80 μm, with an average of 44.3 μm, and which accounted for a relative surface porosity of about 40.9%.



(a) (b)

Figure 5: SEM images of a coir fiber with (a) 100x and (b) 500x of magnification [17]

Figure 6 shows an EDS spectrum performed at a micro region of the fiber's surface in Figure 5. This spectrum reveals that the coir fiber is essentially composed of

carbon, as any organic matter, as well as oxygen and calcium. The calcium is associated with the protrusions in Figure 4. The gold peaks in the spectrum correspond to the sputtered metal used to make the fiber surface an electrical conductor [17].

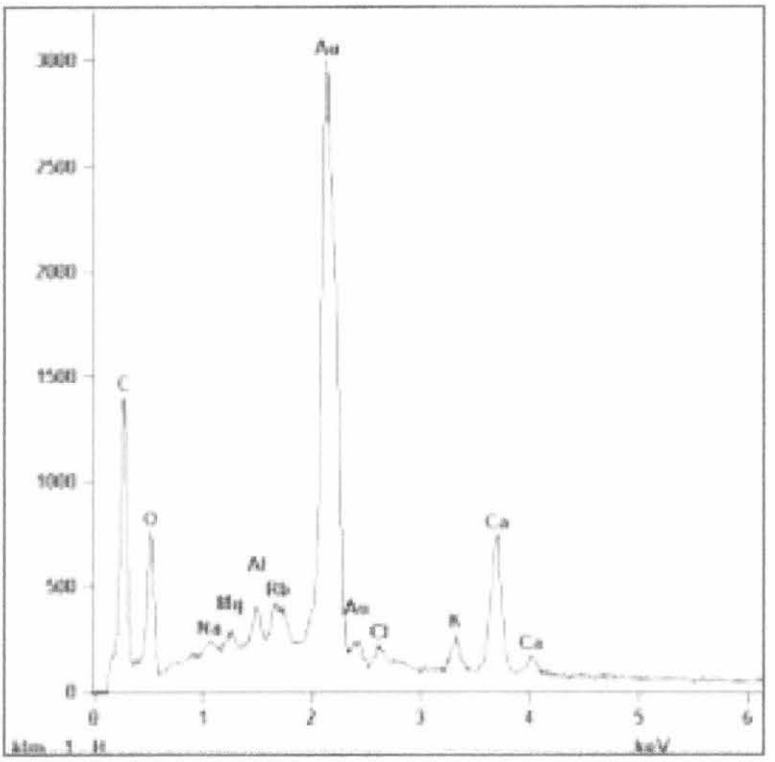


Figure 6: EDS spectrum for a coir fiber [17]

CHAPTER 3

METHODOLOGY

Proper planning and procedures are developed in order to carry out this project. This is to ensure a smooth project flow as well as to accomplish the project's objectives within the time period.

3.1 Data Gathering and Planning

In this stage of the project, any information related to adsorption technology and activated carbon is gathered. The study is focused more on the previous studies related to activated carbon to identify the most suitable method for preparation of activated carbon. The research to determine the efficiency of coconut coir activated carbon is also conducted. That information is obtained from journals, website-related topic, and text books.

3.2 Hazard Analysis

Hazard analysis is conducted before starting any work process to ensure a safe work flow is practiced. The analysis in focused on hazard at the workplace area as well as while conducting the experiment and its prevention. The hazard analysis for every work procedure is summarized in Table 2.

While entering the laboratory area, proper PPE must be worn to as one of safety precaution. The basic PPE is fully covered shoes and lab coat. No contact lenses or jewellery are allowed to be worn inside the laboratory while conducting experiments.

Table 3: Hazard Analysis of Work Process

Work Process	Safety Precaution
• Using grinding machine to grind the coconut coir	• Wearing gloves to avoid the sharp blade of grinding machine • Under supervision of laboratory technologist
• Usage of oven (110°C)	• Wearing gloves when taking out the sample from the oven
• Usage of fixed bed activation unit (700-900°C)	• Let the fixed bed activation unit cool down for at least 3 hours after the burning process • Wearing gloves when taking out the sample from the oven • Under supervision of laboratory technologist
• Preparing KOH solution to treat the coconut coir	• Wearing rubber gloves • Preparing the solution inside laboratory fume hood
• Preparing HCl and NaOH	• Wearing rubber gloves • Preparing the solution inside the laboratory fume hood
• Preparing Cu(II) and Cd(II) solution	• Wearing rubber gloves and mask • Using spatula to take the chemical powder
• Usage of polyvinyl acetate emulsion	• Wearing rubber gloves
• Usage of acid and alkali	• Wearing rubber gloves

Figure 7: Laboratory fume hood

3.3 Preparation of the Absorbent

3.3.1 Preparation of Powdered Coconut Coir Activated Carbon

Material/ Chemical and Equipment Used

Material/ Chemical

- Coconut coir
- 10% potassium Hydroxide (KOH)
- 10% hydrochloric acid (HCl)

Equipment

- Grinder
- Oven
- Fixed bed activation unit

Methodology

The coconut coir is sieved and ground into smaller sizes before it is washed several times with distilled water and dried at 110°C for 24 hours. For the preparation of chemically activated carbon, the coconut coir is treated by soaking it overnight in 10% potassium hydroxide (KOH) solution. The treated coconut coir is then repeatedly washed with distilled water to remove the free KOH and dried at 110°C

for 24 hours. It is subjected to activation by placing in fixed bed activation unit for 30 minutes at 750°C with 0.3 m^3/min nitrogen gas flow. The carbon obtained is repeatedly washed with distilled water and then with 10% hydrochloric acid to neutralize the KOH. The carbon is washed again with distilled water to remove the free acid and dried at 110°C. The carbon is ground to a finer size by using mortar and pestle, and particle size of 0.2 to 0.3 mm which is retained to 80%, is used for further studies. Shown in Figure 2 is the furnace used to activate the carbon at 750°C while Figure 3 is the oven used for the drying purpose.

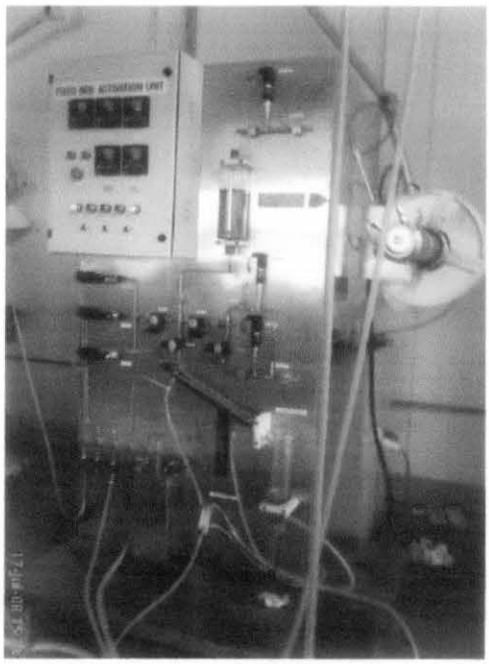


Figure 8: Fixed bed activation unit

Figure 9: Oven for drying at 110°C

3.4 Preparation of Aqueous Solution

3.4.1 Preparation of Cadmium Solution

Standard solution of cadmium with 1000 mg/L concentration is prepared by dissolving 2.7443 g cadmium salt $Cd(NO_3)_2.4H_2O$ in 1000 mL of distilled water. This standard solution is diluted into specific concentration for further investigation.

3.4.2 Preparation of Copper Solution

Standard solution of copper with 1000 mg/L concentration is prepared by dissolving 3.9292 g copper salt $CuSO_4.5H_2O$ in 1000 mL of distilled water. This standard solution is diluted into specific concentration for further investigation. Figure 4 shows the copper salt which is used in this study.

Figure 10: Copper salt

3.5 Determination of Physicochemical Characteristic of the Carbon

3.5.1 Scanning Electron Microscopic Photograph

The SEM photographs of the coconut coir activated carbon are obtained by using Leo 1430 VPSEM. Small amount of the prepared carbon is put on the sample plate before it is examined.

Figure 11: Leo 1430 VPSEM

3.5.2 Ash Content

The ash content of the carbon is determined by burning approximately 1 g of the powdered coconut coir activated carbon at 900°C for 12 hours in a muffle furnace. The initial weight of the carbon and the weight of the remaining ash are recorded [18]. The percentage of as content is calculated as follow:

$$\% ash = \frac{Weight\ of\ ash \times 100\%}{Weight\ of\ original\ Sample} \quad [10]$$

Figure 12: Muffle furnace

3.5.3 pH Measurement

The pH of the carbon is determined by immersing 1.0 g sample in 100 ml of distilled water and stirring for 1 hour before the pH of slurry is taken [19].

Figure 13: pH meter

3.5.4 Apparent Density

Apparent density measurement is conducted using Ultrapycnometer 1000. The activated carbon is loaded inside the sample cell and the initial weight is taken. After keyed in the initial weight the sample is purged and automatically analyzed with no operator involvement.

Figure 14: Ultrapycnometer 1000

3.5.5 Moisture Content

The moisture content of the coconut coir activated carbon is measured using moisture content analyzer. Small amount of carbon is loaded inside the cell and the initial weight is taken. The carbon is then heated for 105°C for 15 minutes. The weight of remaining carbon after heating is measured. The percentage of moisture content is calculated as below:

$$\% \text{ moisture content} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Weight of original Sample}} \times 100\%$$

Figure 15: Moisture content analyzer

3.6 Adsorption Studies

3.6.1 Batch Studies

Material/ Chemical and Equipment Used

Material/ Chemical

- Whatman 450 µm filter paper
- 20 and 40 mg/L Cd(II) solution
- 20 and 40 mg/L Cu(II) solution
- 0.1 N NaOH and HCl

Equipment

- pH meter
- Rotary mechanical shaker
- Atomic adsorption spectrophotometer (AAS)

Methodology

Batch studies is carried out by adding 0.1 g of powdered coconut coir activated carbon to a series of flasks containing 100 mL of Cd(II) or Cu(II) solution with specific concentration. The initial pH of the solution after being mixed well with the carbon is taken. The solutions are equilibrated in a rotary mechanical shaker at 150 rpm and 25°C. The progress of the adsorption during the course of the experiment is determined by taking aliquots after desired contact time, filtering through Whatman 450 µm filter paper, and by assessing the metal concentration. The pH of the solution after filtration is taken.

The metal concentration is determined by using AAS where two vials is taken and filled with 10 mL of the solution. The average metal concentration from these two samples is recorded. The amount of the metal ion adsorbed is computed as

$$Adsorbate\ uptake\ (\%) = \frac{(C_o - C_t)}{C_o}\ x\ 100 \qquad [21]$$

where C_o and C_t are the initial and at time *(t)* of the adsorbent concentration, respectively.

For copper the concentration of standard AAS used are 1, 5 and 10 ppm. While for cadmium the standard AAS are in concentration 0.5, 1 and 3 ppm. The influence of experimental variables, such as contact time, solution concentration, carbon dose and pH are evaluated.

The contact time is varied from 1 hour to 6 hours for both 20 mg/L and 40 mg/L solution concentration. To determine the influence of carbon dose, 40 mg/L solutions are added with different amount of carbon varies from 2 mg to 10 mg. The pH of the solutions are adjusted by using 0.1 N NaOH or 0.1 N HCl and varied from pH 3 to 12.

3.6.2 Adsorption isotherm models

The experimental adsorption isotherm data were obtained in the batch adsorbed by contacting 1 g of prepared coconut coir activated carbon with 100 ml of known initial concentration of copper and cadmium aqueous solution. The pH of the solution which its concentration is varied from 10 to 100 mg/L is adjusted until it reached pH 6 using 0.1 NaOH and HCl.

The same method is also conducted using commercially activated carbon. Filtrsorb 400 (F-400) is used in this study. F-400 is manufactured by Calgon Carbon Corporation using bituminous carbon and is activated at 800 to 1100°C. [22]

Figure 16: Rotary machine

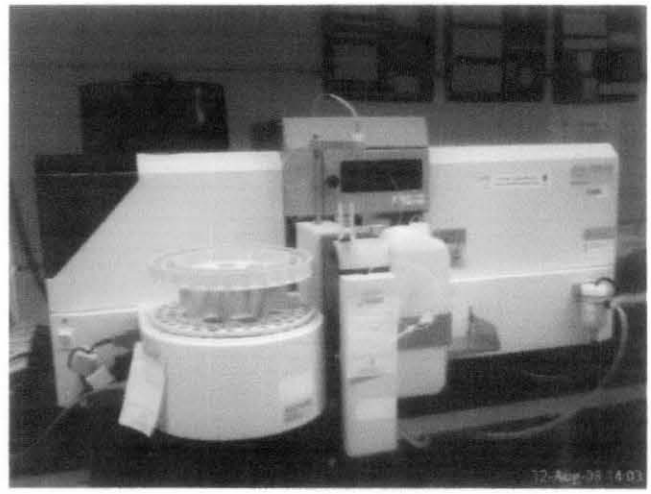


Figure 17: Atomic Adsorption Spectrophotometer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physicochemical Characteristic of the Carbon

Some of the tests to determine the physicochemical characteristic of the prepared coconut coir carbon have been conducted. The results obtained are shown as below.

4.1.1 SEM Photograph

Shown below are the SEM photograph obtained from the coconut coir activated carbon

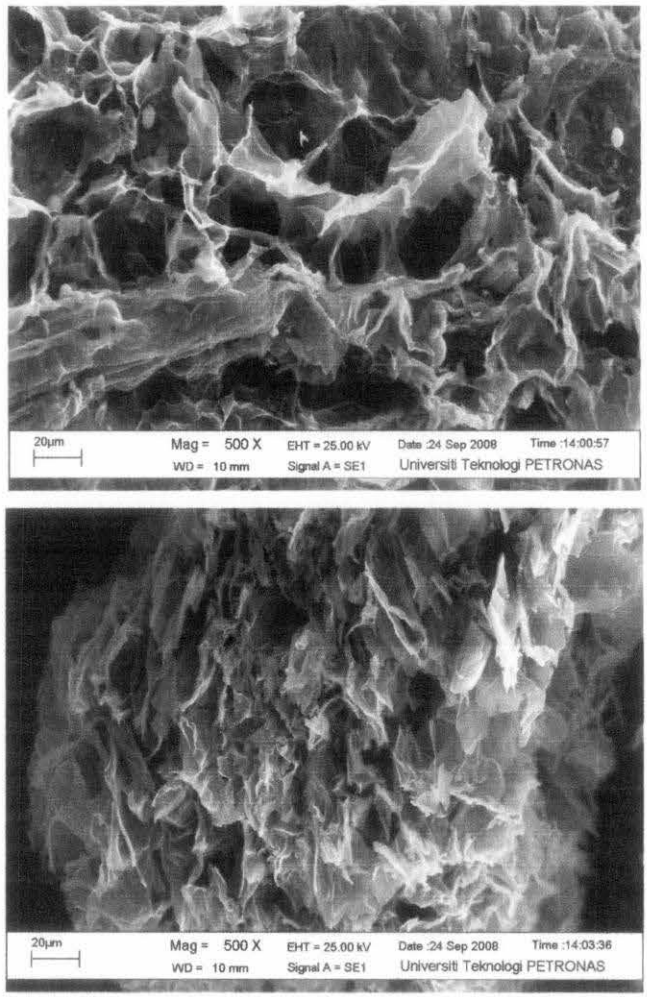


Figure 18: SEM photographs with 500x magnification

4.1.2 pH Measurement

Below are the readings of pH for coconut coir carbon for all the prepared samples.

Table 4: pH of the carbon

Sample	pH
1	8.320
2	8.046
3	8.012
4	8.122
5	8.224

4.1.3 Apparent Density

Table 4 summarized the density of prepared carbon which was obtained from Ultrapycnometer 1000. The reading printed from the equipment was attached in Appendix IV.

Table 5: Apparent density of the carbon

Sample	Density, g/cm^3
1	0.2412
2	0.2516
3	0.2544
4	0.2440
5	0.2480

4.1.4 Ash content

To determine the ash content of the carbon, 125 mL size porcelain bowl was used. The initial weight of the bowl was recorded before and after burning at 900°C. The calculation to determine the ash content is shown in Table 6.

Table 6: Ash content of the carbon

Parameter	Mass, g
Weight of the porcelain bowl	27.4197
Initial weight of the porcelain + sample	28.4197
Final weight of porcelain + sample	27.4525

$$\frac{27.4525-27.4197}{28.4197-27.4197}\times 100\% = 3.28\%$$

4.1.5 Moisture content

The calculation to determine the moisture content of the coconut coir activated carbon is shown as below. The printed reading from the analyzer is attached in Appendix V.

Table 7: Moisture content analysis

Parameter	Mass, g
Initial weight of sample	0.971
Final weight of sample after heating	0.931

$$\frac{0.971-0.931}{0.971}\times 100\% = 4.12\%$$

4.1.6 Comparison with Coconut Coir Pith Activated Carbon (Santhy and Selvapathy, 2004)

The results of all the characterization tests are summarized and compared with the coconut coir pith activated carbon characteristic from Santhy, K. and Selvapathy, P. (2004) in Table 8.

Table 8: Comparison of coconut coir carbon and coconut coir pith carbon (Santhy and Selvapathy, 2004)

Characteristic	Coconut coir AC	Coconut coir pith AC
pH	8.1	8.2
Apparent density, g/cm^3	0.25	0.19
Ash content, %	3.28	2.04
Moisture content, %	4.1	8.9

From the comparison made, pH of both carbons is almost the same. Yet the prepared coconut coir activated carbon has higher ash content and is heavier compare to coconut coir pith activated carbon (Santhy and Selvapathy, 2004).

4.2 Batch Study

4.2.1 Effect of contact time and initial concentration

The initial test to check the efficiency of coconut coir activated carbon was done by conducting batch test. Experimental studies were carried out by varying initial concentrations of copper and cadmium ion solution and its contact time. 20 mg/L and 40 mg/L of both copper and cadmium solution were used and equilibrated in a rotary mechanical shaker from contact time ranging from 1 hour to 6 hours.

Table 9: Effect of contact time on removal of copper ion

Contact Time, hrs	Initial concentration= 20mg/L		Initial concentration = 40 mg/L	
	Final concentration	% Removal	Final concentration	% Removal
1	11.980	40.10	28.085	29.79
2	7.346	63.27	17.536	56.16
3	0.284	98.58	10.334	74.16
4	0.237	98.82	8.740	78.15
5	0.218	98.91	7.156	82.11
6	0.208	98.96	4.692	88.27

Table 10: Effect of contact time on removal of cadmium ion

Contact Time, hrs	Initial concentration= 20mg/L		Initial concentration = 40 mg/L	
	Final concentration	% Removal	Final concentration	% Removal
1	9.574	53.13	26.016	34.96
2	5.756	71.22	15.379	61.55
3	0.822	95.89	8.744	78.14
4	0.704	96.48	8.747	78.13
5	0.378	98.11	4.617	88.46
6	0.136	99.32	3.586	91.01

The effect of initial concentration and contact time on the removal efficiency of copper and cadmium ion are shown in Figure 19 and 20. It is evident from the figures that the percentage removal of heavy metal decreases as the concentration of the metal ions increase. Increase in the contact time has increases the uptake of metal ions. The rate uptake for the first two hours is very fast. However, at the three hours contact time, the uptake reached equilibrium for both cadmium and copper ion.

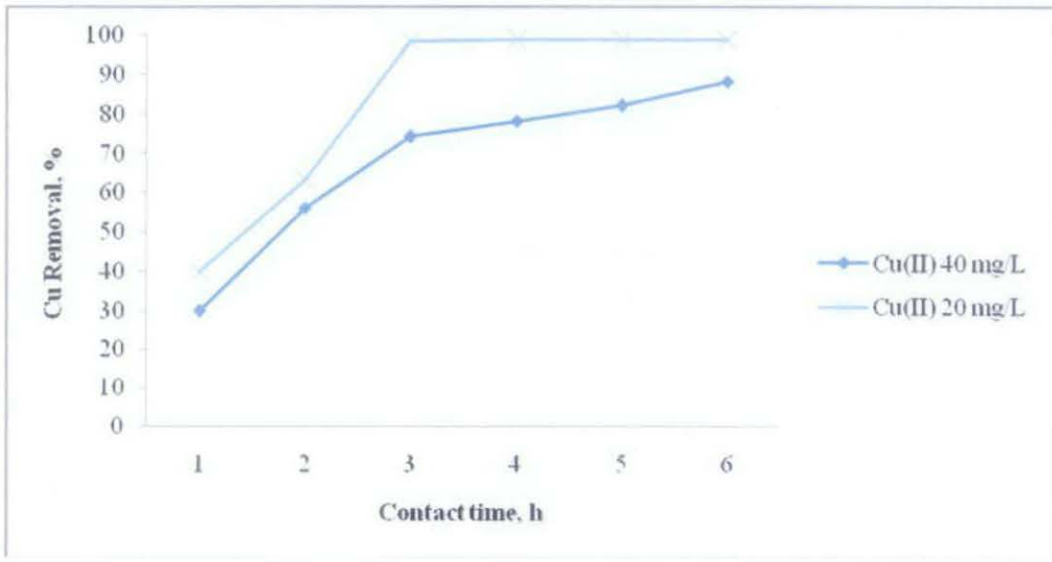


Figure 19: Effect of initial concentration and contact time on adsorption of Cu(II) by coconut coir activated carbon

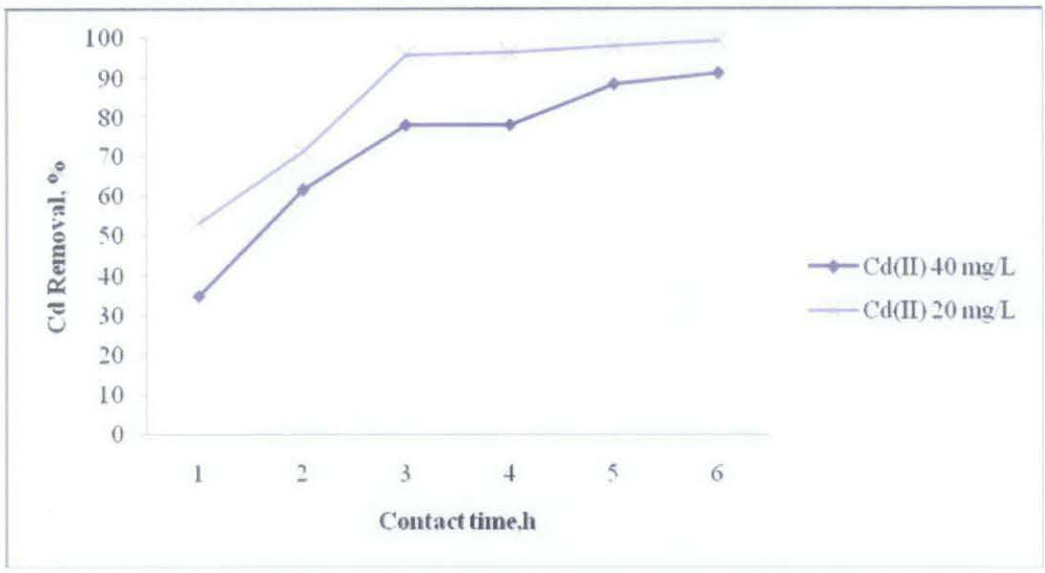


Figure 20: Effect of initial concentration and contact time on adsorption of Cd(II) by coconut coir activated carbon

4.2.2 Effect of pH

The pH of both 40 mg/L copper and cadmium ion are adjusted using 0.1 N NaOH and 0.1 N HCl. The contact time used is three hours at which the solution reached equilibrium. The results obtained are summarized in Table 11.

Table 11: Effect of pH on adsorption of copper and cadmium ion by coconut coir activated carbon

pH	Percentage Removal, %	
	Cu(II)	Cd(II)
3	28.44	33.72
5	32.78	47.82
6	79.25	71.77
7	85.17	83.91
8	91.66	89.43
9	95.32	93.11
10	99.02	98.67

Figure 21 represents the effect of pH on adsorption of copper and cadmium ion by coconut coir activated carbon. From the figure, the adsorption is very low at acidic pH and increases with increasing pH. The results show that adsorption is the major

removal step in the metal ions, at least in the less than natural pH region. Although chemical precipitation might occur at the pH 8 up to 10 yet, it is not the major metal mechanism.

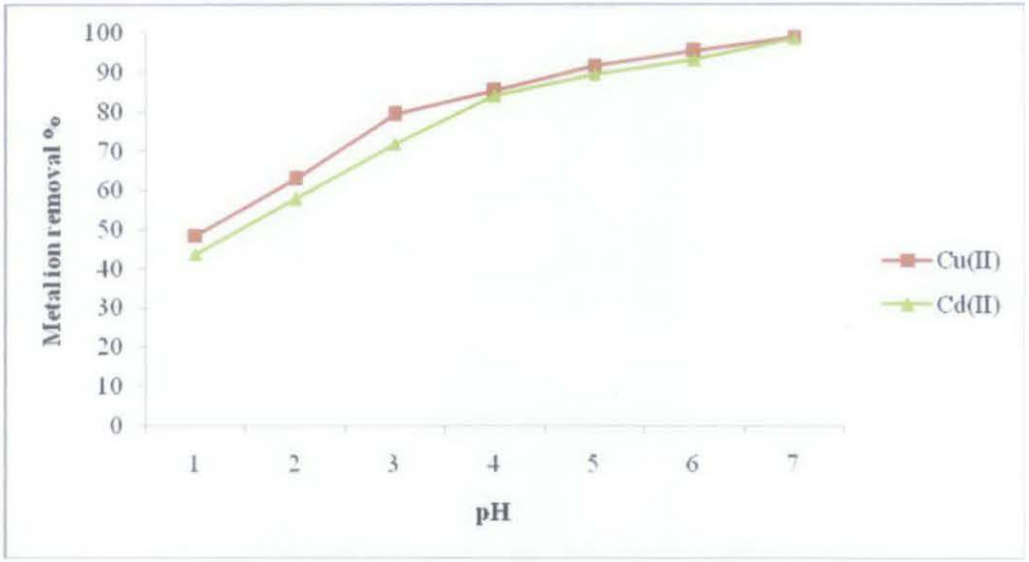


Figure 21: Effect of pH on adsorption of metal ions by coconut coir activated carbon

4.2.3 Effect of carbon dose

To study the effect of the carbon dosage on the removal of copper and cadmium, the amount of coconut coir activated carbon is varied for every flask. The copper and cadmium ion solution used is in concentration 40 mg/L at pH 6 which is at the optimum condition. The result obtained from the study of effect of carbon dosage is summarized in Table 12.

Table 12: Effect of carbon dosage on adsorption of copper and cadmium ion by coconut coir activated carbon

Carbon Dose, mg	Percentage Removal, %	
	Cu(II)	Cd(II)
2	35.89	28.95
4	46.17	53.22
6	65.52	61.11
8	76.69	66.52
10	87.17	89.01

The result is summarized in Figure 22. From the figure, it is proved that the percentage removal of copper and cadmium ion increase as the carbon dosage increase.

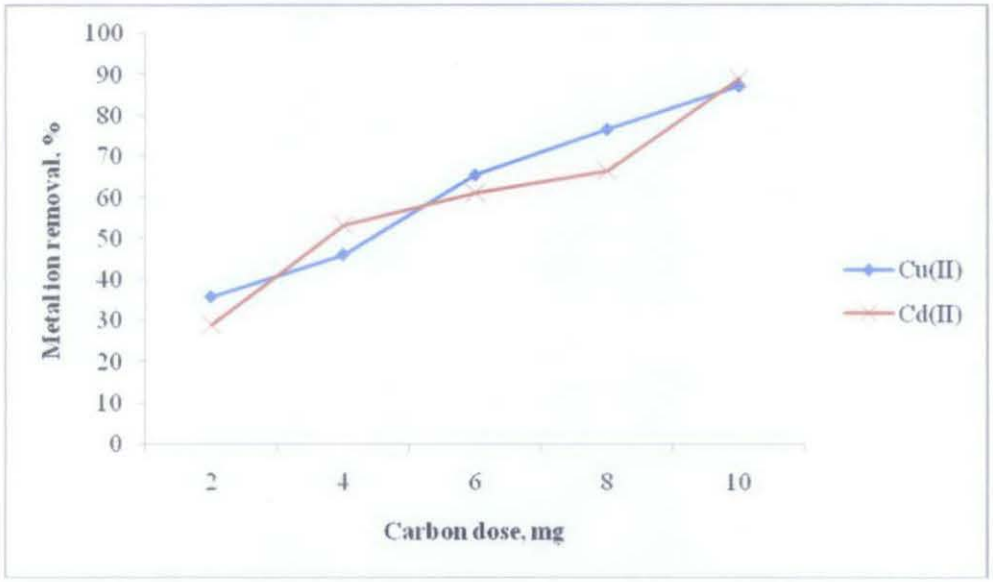


Figure 22: Effect of carbon dose on adsorption of copper and cadmium ion by adsorption coconut coir activated carbon

4.3 Adsorption Isotherm

The adsorption isotherm was conducted by using ten different concentrations of copper and cadmium solution varying from 10 mg/L to 100 mg/L. pH of all solutions were adjusted to pH 6. It was equilibrated for 3 hours after 10 mg of coconut coir activated carbon is added inside 100 mL of the solution. The final concentration of the solution was measured. The same test was done using F-400. The data obtained were fitted with Freundlich and Langmuir adsorption isotherm.

The calculation for both of these adsorption isotherms was attached in Appendix VII.

4.3.1 Freundlich Isotherm

Shown in Figure 23 and 24 are the best straight line plots for copper and cadmium ion. This indicated that the adsorption process for both ions follow the Freundlich type.

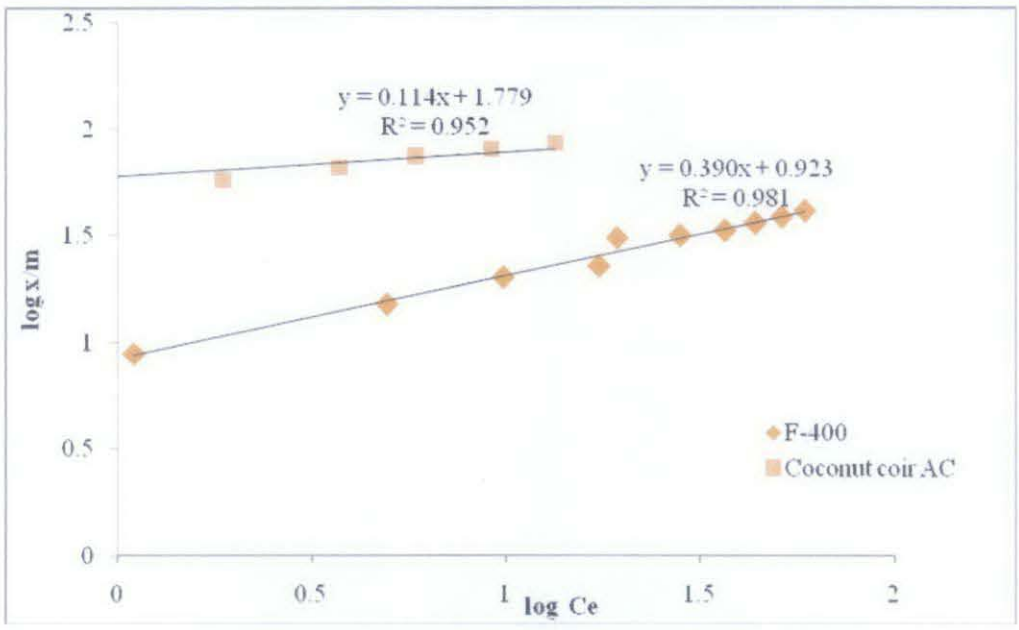


Figure 23: Freundlich isotherm for Cu(II)

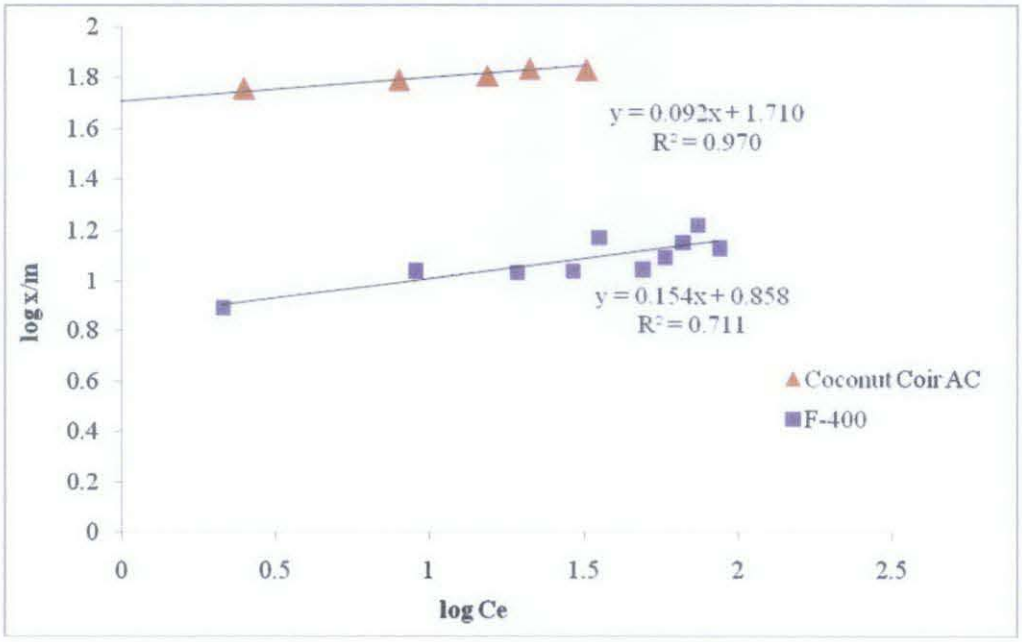


Figure 24: Freundlich isotherm for Cd(II)

The value of *K* (y-intercept) and *1/n* (slope) which indicating the adsorption capacity and adsorption rate are shown in Table 13. The values are compared with F-400 and coconut coir pith activated carbon (Santhy and Selvapathy, 2004).

Table 13: Intercept and slope values of Freundlich isotherm

Carbon Type	Cu(II)		Cd(II)	
	1/n	K	1/n	K
Coconut Coir	0.114	60.117	0.087	51.641
Coconut Coir Pith	0.100	89.700	0.080	58.800
F-400	0.390	8.375	0.154	7.211

From the results obtained, it is shown that the adsorption capacity of coconut coir activated carbon is much higher compare to F-400. Yet, the value is lower compare to coconut coir pith activated carbon (Santhy and Selvapathy, 2004). The adsorption rate of F-400 is higher for both copper and cadmium ion. The coconut coir activated carbon has slightly higher adsorption rate compare to coconut coir activated carbon (Santhy and Selvapathy, 2004).

4.3.2 Langmuir Isotherm

The same experimental adsorption data was fitted to Langmuir isotherm. The plotted graphs are shown in Figure 25 and 26.

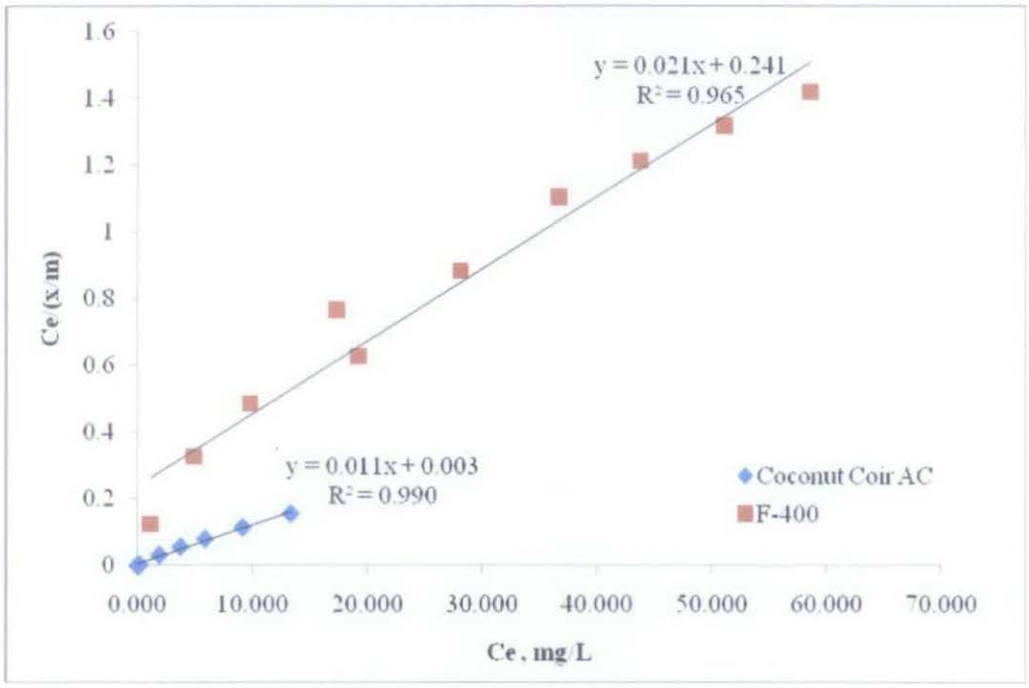


Figure 25: Langmuir isotherm for Cu(II)

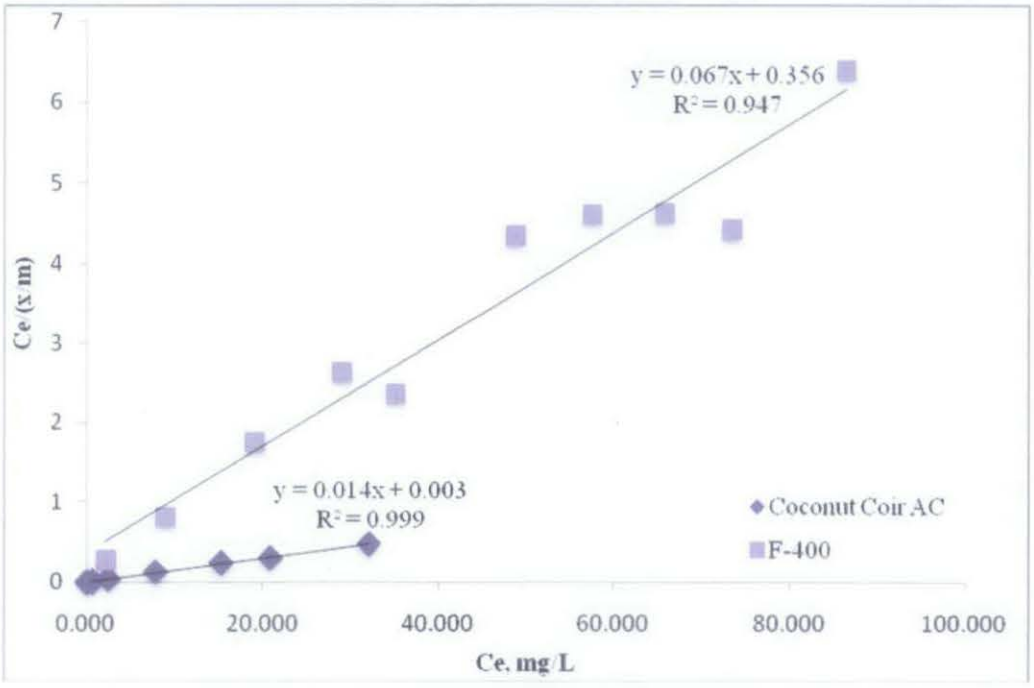


Figure 26: Langmuir Isotherm for Cd(II)

The empirical constants *a* and *b* are calculated by determining the slope and y-intercept value of the best-fit line. The empirical constants of both coconut coir activated carbon and F-400 are summarized in Table 14.

Table 14: Empirical constant of Langmuir isotherm for coconut coir activated carbon and F-400

Carbon Type	**Cu(II)**		**Cd(II)**	
	a	**b**	**a**	**b**
Coconut Coir	90.909	3.6667	71.429	4.6667
F-400	47.619	0.0871	14.95	0.1882

From both of these isotherms, it is shown that the adsorption data was best fitted to Langmuir isotherm compare to Freundlich isotherm.

CHAPTER 5

CONCLUSIONS

The present investigation has revealed that activated carbon prepared by KOH treatment of coconut coir can be used to adsorb copper and cadmium. From the batch studies, it is evident that as the concentration of the metal ion increases, the uptake of metal ion by coconut coir activated carbon decreases. The percentage removal of metals ion increases as the contact time increases and reach equilibrium at three hours contact time. By varying the pH of heavy metal solution, the uptake is lower at acidic condition and increases as the pH of the solution increases. Although the chemical precipitation might contribute in the percentage removal of the metal ion for pH 8 up to 10, it is not the main metal mechanisms. The results show that adsorption is the major removal step in the metal ions, at least in the less than natural pH region. By studying the effect of carbon dosage to the percentage removal of metal ions, it is proven that as the carbon dosage increases, the percentage removal of the metal ions also increases.

Comparing the characteristic of coconut coir activated carbon with coconut coir pith activated carbon (Santhy and Selvapathy, 2004) pH of both carbons is almost the same. Yet the prepared coconut coir activated carbon has higher ash content and is heavier compare to coconut coir pith activated carbon.

From the adsorption isotherms, coconut coir activated carbon is very much better to adsorb copper and cadmium compared to commercially activated carbon. The adsorption capacity of coconut coir activated carbon is much higher compared to F-400. Yet, the value is lower compared to coconut coir pith activated carbon (Santhy and Selvapathy, 2004). The adsorption rate for both copper and cadmium ion by F-400 is higher. The coconut coir activated carbon has slightly higher adsorption rate compare to coconut coir pith activated carbon (Santhy and Selvapathy, 2004).

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The comparison is made between adsorption of coconut coir activated carbon with precipitation which is the most common method used to remove heavy metal in wastewater. The comparison of these methods is summarized as below:

Table 15: Comparison of Adsorption by coconut coir activated carbon with precipitation

PARAMETER	ADSORPTION COCONUT COIR AC	PRECIPITATION
• Minimum amount of copper and cadmium remaining after treatment	0 mg/L	• Copper = 0.01mg/L • Cadmium =0.05mg/L
• Major drawback after treatment	none	Sludge formation
• Effectiveness with different type of heavy metals	Copper and cadmium can be removed at pH 6	• Not effective as minimum solubility of different metals at different pH

The table above shown that adsorption by coconut coir activated carbon is much more effective method to remove heavy metals compare to precipitation.

From all of the studies, it is proven that coconut coir activated carbon is an excellent adsorbate to remove copper and cadmium and can be used in waste water treatment process.

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APPENDICES

APPENDIX I

GANTT CHART

Table 16: Gantt chart

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Preparation of Coconut Coir AC											Mid Semester Break						
2	Batch Studies																	
3	Submission of Progress Report					●												
4	Characterization of Coconut Coir AC																	
5	Adsorption Isotherms																	
7	Poster Presentation												●					
8	Submission of Dissertation Report													●				
9	Final Oral Presentation															●		
10	Submission of Hardbound																	●

● Milestone

Process

APPENDIX II

Calculation of standard solution with concentration 1000 mg/L

- ***For 1000 mg/L copper ion solution using $CuSO_4.5H_2O$***

  - Molecular weight of $CuSO_4.5H_2O$

$$MW = 63.546 + 32.065 + 4(15.9994) + 5[2(1.00794) + 15.9994]$$
$$= 249.685$$

$$\frac{249.685}{63.546} = 3.9292g$$

For 1000 mg/L copper ion, 3.9292 g copper salt $CuSO_4.5H_2O$ is dissolved in 1000 mL of distilled water

- ***For 1000 mg/L copper ion solution using $Cd(NO_3)_2.4H_2O$***

  - Molecular weight of $Cd(NO_3)_2.4H_2O$

$$MW = 112.411 + 2[14.0067 + 3(15.9994)] + 4[2(1.00794) + 15.9994]$$
$$= 308.48192$$

$$\frac{308.48192}{112.411} = 2.7443g$$

For 1000 mg/L copper ion, 2.7443 g copper salt $Cd(NO_3)_2.4H_2O$ is dissolved in 1000 mL of distilled water

APPENDIX III

Solution preparation for acid and alkali

- ***For 10% HCl with initial concentration 95%***

$$M_1V_1 = M_2V_2$$

$$V_1 = \frac{(10\%)(1000ml)}{95\%}$$

$$V_1 = 105.26ml$$

- *105.26 ml of HCl with initial concentration 95% is needed to be diluted with distilled water to produce 10% HCl*

- ***For 0.1 N HCl with initial concentration 95%***

Given:

MW HCl = 36.5 g/mole

Density HCl = 1.19 g/ml

Normality = molarity x n

As n = 1 (for HCl)

Nomality = molarity

$$Molarity = \frac{density \times concentration \times 10}{molecular\ weight}$$

$$= \frac{1.19 \times 95 \times 10}{36.5} = 30.973M$$

Molarity of 95% HCl is 30.973 M

Thus, to calculate 0.1 M = 0.1 N

$$V_1 = \frac{(0.1M)(1000ml)}{30.973M}$$

$$V_1 = 3.229ml$$

APPENDIX IV

DENSITY READING OF COCONUT COIR ACTIVATED CARBON PRINTED FROM ULTRA PYCNOMETE

QUANTACHORME CORPORATION
Ultrapycnometer 1000 Version 2.2
Analysis Report

Sample & User Parameters

Sample ID: AC
Weight: 0.0650 grams
Analysis Temperature: 33.0 degC

Date: 07-18-08
Time: 12:09:35
User ID: HAIDA

Analysis parameters

Cell Size: Small
V added - Small: 12.4554 cc
V cell: 20.9726 cc
Target Pressure: 19.0 psi
Equilibrium Time: Auto
Flow Purge: 1:00 min
Maximum Runs: 5
Number of Runs Averaged: 5

Results

Deviation Requested: 0.005 %
Average Volume: 0.2623 cc
Average density: 0.2478 g/cc
Coefficient of Variation: 2.0832 %

Deviation Achieved: +/- 0.940
Std. Dev. : 0.0055 cc
Std. Dev. : 0.0516 g/cc

Tabular Data

RUN	VOLUME (cc)	Density (g/cc)
1	0.2693	0.2412
2	0.2583	0.2516
3	0.2555	0.2540
4	0.2664	0.2440
5	0.2621	0.2480

APPENDIX V

MOISTURE CONTENT READING PRINTED FROM MOISTURE CONTENT ANALYZER

APPENDIX VI

ASS STANDARD CURVE

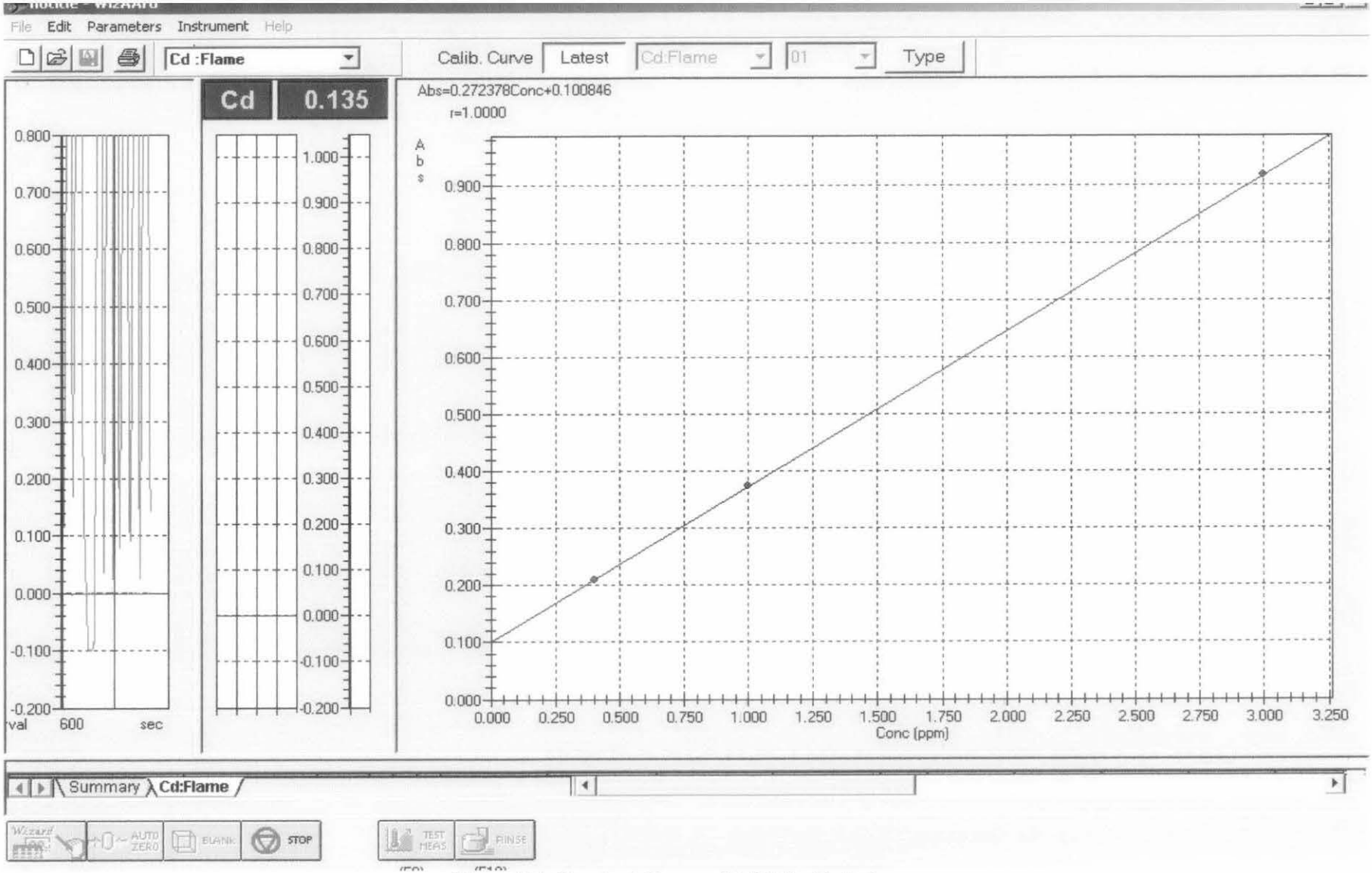

Figure 27: Standard Curve of ASS for Cadmium

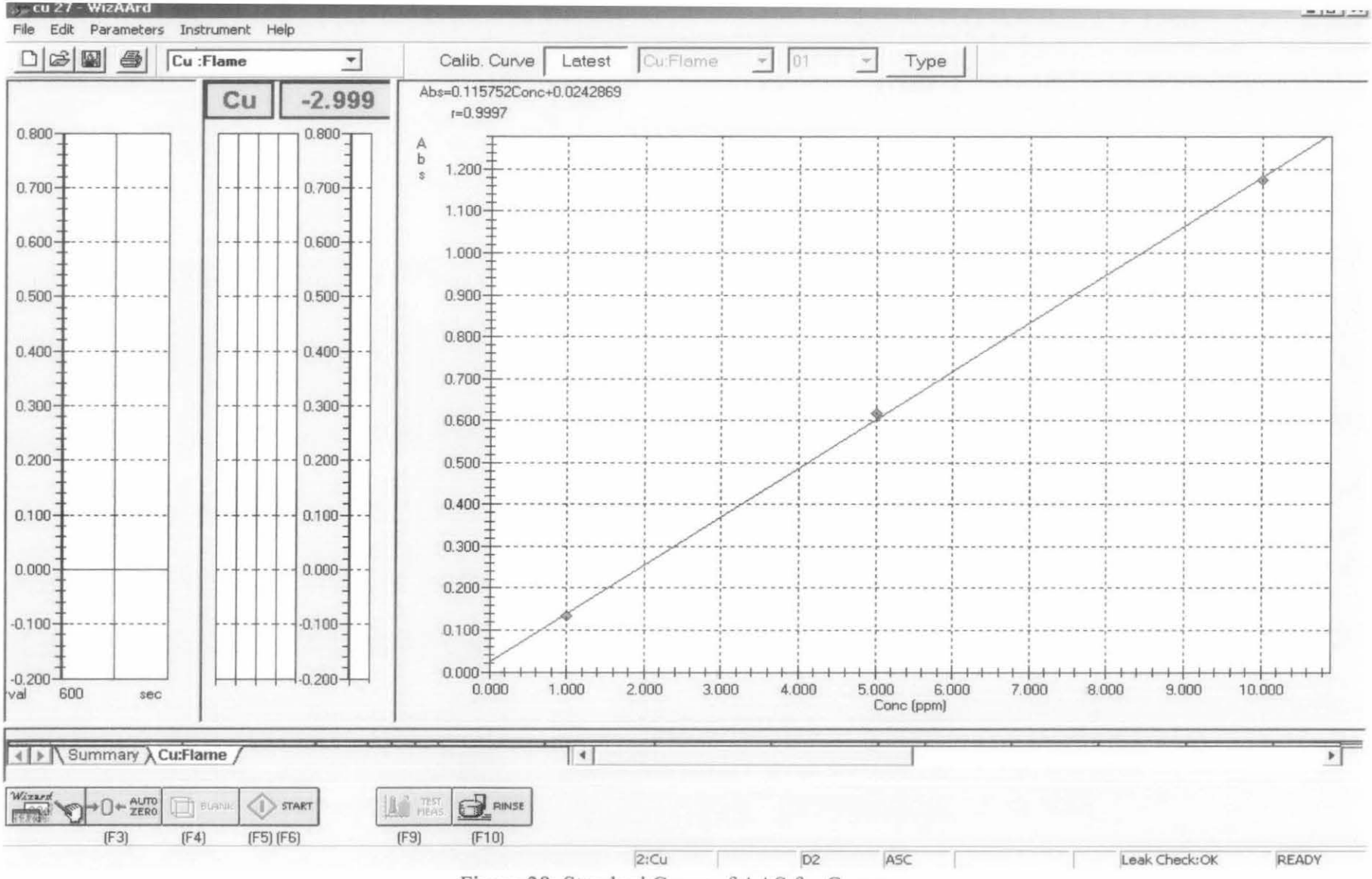

Figure 28: Standard Curve of AAS for Copper

APPENDIX VII

CALCULATION FOR FREUNDLICH AND LANGMUIR ADSORPTION ISOTHERM

Copper ion- Coconut coir activated carbon

Co	Ce	Co-Ce	(Co-Ce)/Co	V	(Co-Ce)V	m	x/m	Ce/(x/m)	log Ce	log (x/m)
10	0.000	10	1.0000	0.05	0.5	0.05	10	0	#NUM!	1
20	0.000	20	1.0000	0.05	1	0.05	20	0	#NUM!	1.30103
30	0.000	30	1.0000	0.05	1.5	0.05	30	0	#NUM!	1.4771213
40	0.021	39.979	0.9995	0.05	1.99895	0.05	39.979	0.000525	-1.67778	1.6018319
50	0.172	49.828	0.9966	0.05	2.4914	0.05	49.828	0.003452	-0.76447	1.6974735
60	1.876	58.1237	0.9687	0.05	2.906185	0.05	58.1237	0.032281	0.273302	1.7643533
70	3.734	66.2665	0.9467	0.05	3.313325	0.05	66.2665	0.056341	0.572116	1.821294
80	5.878	74.1221	0.9265	0.05	3.706105	0.05	74.1221	0.0793	0.769222	1.8699477
90	9.145	80.8548	0.8984	0.05	4.04274	0.05	80.8548	0.113106	0.961193	1.9077058
100	13.346	86.6545	0.8665	0.05	4.332725	0.05	86.6545	0.154008	1.125335	1.9377911

Copper ion- F400

Co	Ce	Co-Ce	(Co-Ce)/Co	V	(Co-Ce)V	m	x/m	Ce/(x/m)	log Ce	log (x/m)
10	1.102	8.898	0.8898	0.05	0.4449	0.05	8.898	0.123848	0.042182	0.9492924
20	4.922	15.078	0.7539	0.05	0.7539	0.05	15.078	0.326436	0.692142	1.1783437
30	9.806	20.194	0.67313325	0.05	1.0097	0.05	20.194	0.48559	0.991492	1.305222
40	17.325	22.67501	0.56687524	0.05	1.13375	0.05	22.67501	0.764057	1.238673	1.355547
50	19.256	30.744	0.61487998	0.05	1.5372	0.05	30.744	0.626334	1.284566	1.48776
60	28.118	31.882	0.53136667	0.05	1.5941	0.05	31.882	0.88194	1.448984	1.5035456
70	36.699	33.301	0.47572861	0.05	1.66505	0.05	33.301	1.102039	1.564654	1.5224573
80	43.811	36.189	0.45236246	0.05	1.80945	0.05	36.189	1.210617	1.641583	1.5585766
90	51.133	38.867	0.43185552	0.05	1.94335	0.05	38.867	1.315589	1.708701	1.589581
100	58.623	41.37701	0.41377005	0.05	2.06885	0.05	41.37701	1.416801	1.768068	1.61676

Cadmium ion- Coconut coir activated carbon

Co	Ce	Co-Ce	(Co-Ce)/Co	V	(Co-Ce)V	m	x/m	Ce/(x/m)	log Ce	log (x/m)
10	0.000	10	1.0000	0.05	0.5	0.05	10	0	#NUM!	1
20	0.000	20	1.0000	0.05	1	0.05	20	0	#NUM!	1.30103
30	0.004	29.996	0.9999	0.05	1.4998	0.05	29.996	0.000133	-2.39794	1.4770633
40	0.056	39.9441	0.9986	0.05	1.997205	0.05	39.9441	0.001399	-1.25259	1.6014526
50	0.663	49.3368	0.9867	0.05	2.46684	0.05	49.3368	0.013442	-0.17836	1.693171
60	2.486	57.5136	0.9586	0.05	2.87568	0.05	57.5136	0.043232	0.395571	1.7597706
70	7.849	62.1508	0.8879	0.05	3.10754	0.05	62.1508	0.126293	0.894825	1.7934467
80	15.315	64.6853	0.8086	0.05	3.234265	0.05	64.6853	0.236757	1.185108	1.8108056
90	20.889	69.1105	0.7679	0.05	3.455525	0.05	69.1105	0.302262	1.319928	1.839544
100	32.126	67.8739	0.6787	0.05	3.393695	0.05	67.8739	0.47332	1.506858	1.8317028

Cadmium ion- F400

Co	Ce	Co-Ce	(Co-Ce)/Co	V	(Co-Ce)V	m	x/m	Ce/(x/m)	log Ce	log (x/m)
10	2.119	7.8813	0.78813	0.05	0.394065	0.05	7.8813	0.268826	0.326069	0.8965979
20	8.913	11.0873	0.554365	0.05	0.554365	0.05	11.0873	0.803866	0.950009	1.0448258
30	19.076	10.924	0.36413333	0.05	0.5462	0.05	10.924	1.746247	1.280487	1.0383817
40	28.977	11.023	0.275575	0.05	0.55115	0.05	11.023	2.628776	1.462053	1.0422998
50	35.107	14.893	0.29786	0.05	0.74465	0.05	14.893	2.357282	1.545394	1.1729822
60	48.766	11.234	0.18723333	0.05	0.5617	0.05	11.234	4.340929	1.688117	1.0505344
70	57.512	12.488	0.1784	0.05	0.6244	0.05	12.488	4.605381	1.759758	1.0964929
80	65.766	14.234	0.177925	0.05	0.7117	0.05	14.234	4.620346	1.818001	1.153327
90	73.384	16.616	0.18462222	0.05	0.8308	0.05	16.616	4.416466	1.865601	1.2205265
100	86.471	13.529	0.13529	0.05	0.67645	0.05	13.529	6.391529	1.93687	1.1312657

APPENDIX VIII

PROGRESS PICTURES

Figure 29: Coconut coir

Figure 30: Coconut coir before being ground

Figure 31: Coconut coir after being ground

Figure 32: Coconut coir after being washed with distilled water

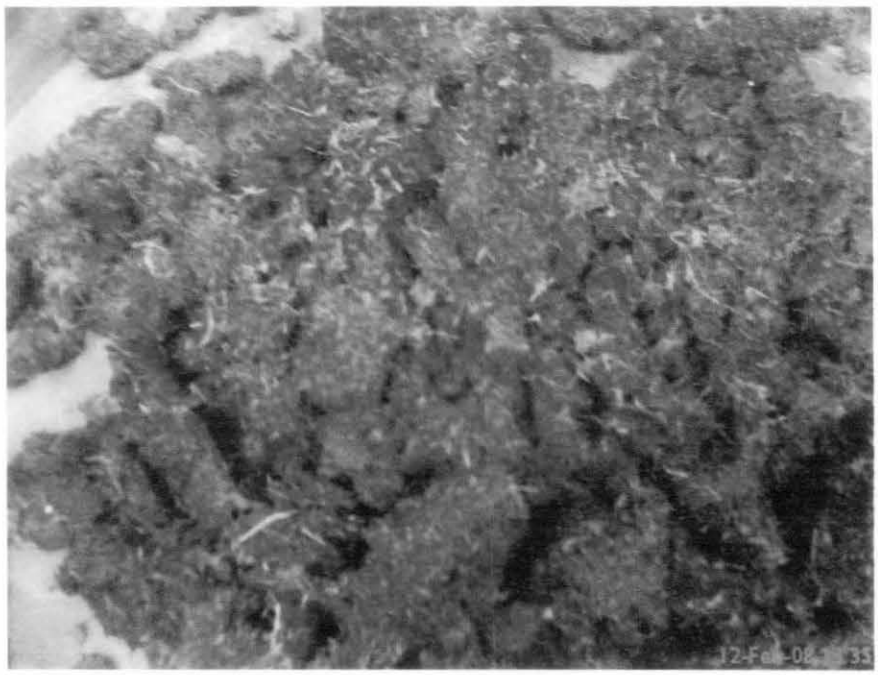

Figure 33: Coconut coir after being dried at 110°C

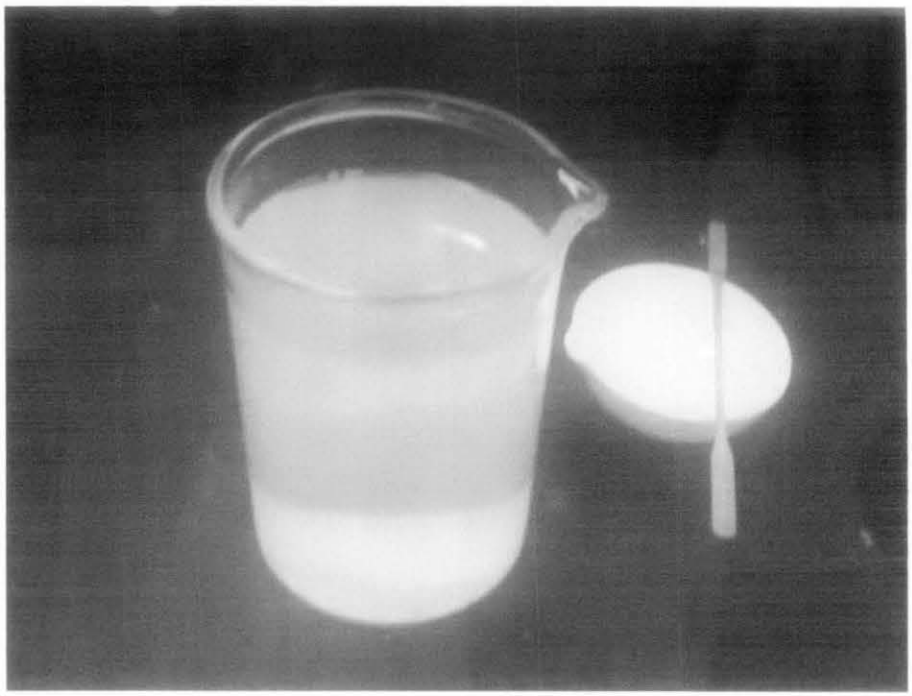

Figure 34: 10% Potassium Hydroxide (KOH)

Figure 35: Coconut coir being submerged inside KOH

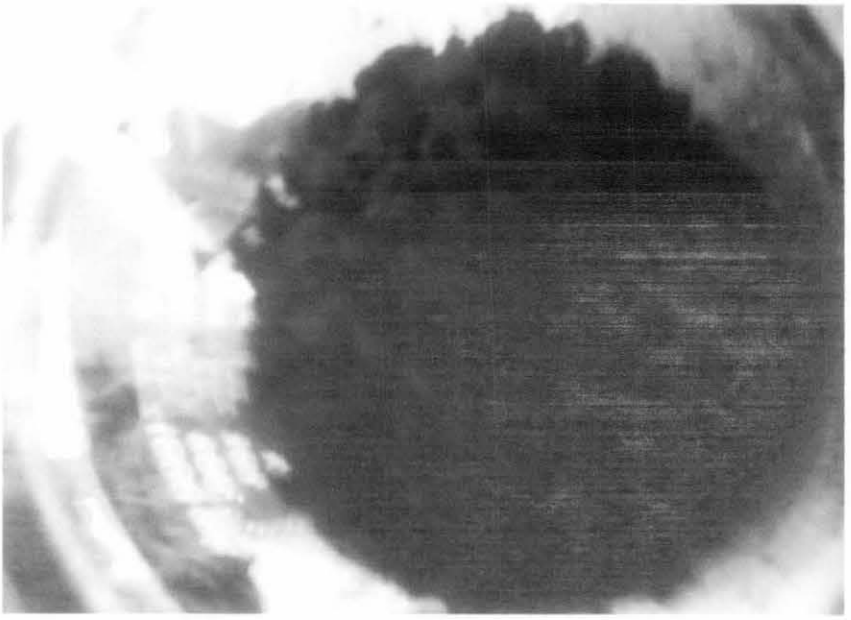

Figure 36: Coconut coir after being submerged inside KOH

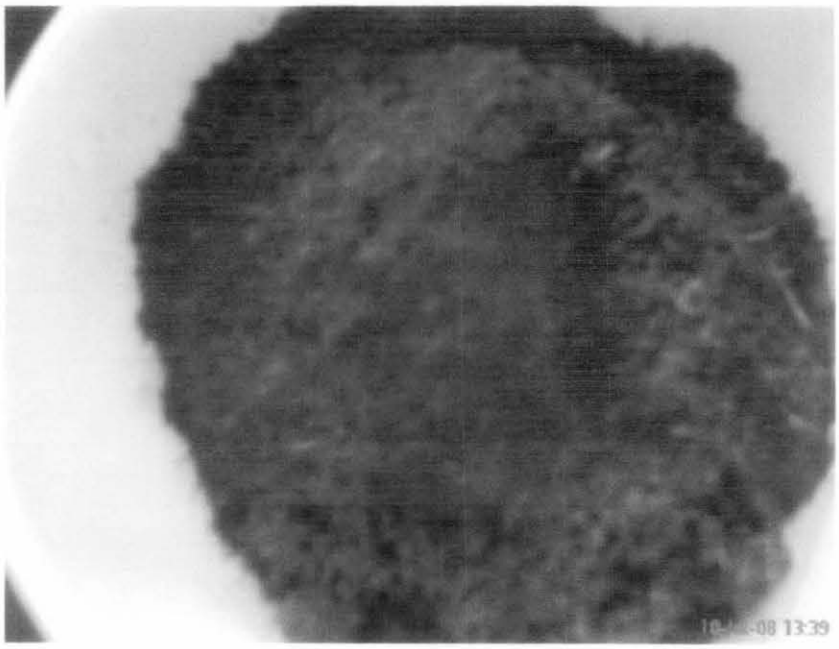

Figure 37: Coconut coir before being burned at 750°C

Figure 38: Coconut coir activated carbon